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MEASUREMENT OF VARIATIONS IN THE INTEGRAL ELECTRON CONCENTRATION ON THE MARS-2 COMMUNICATION LINE BY THE DISPERSION INTERFEROMETER METHOD

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The transmitter of a two-frequency dispersion interferometer was placed on Mars-2 to study the integral characteristics of the space plasma. Two signals of coherent frequencies were emitted during the communication sessions from the space station, and the difference in the phases of these signals was measured at a receiving point on the Earth which equalled

$$\varphi_g = -\frac{e^2}{mcf_0'}(p^2-1)N_n, \qquad (1)$$

where e and m are the charge and mass of the electron; c- speed of light; $N_n=\int_L N\,dl$ - integral electron concentration on the propagation path L; f_0 and f_0' - frequencies of coherent signals which under real experimental conditions lie in the decimeter and centimeter wavelength ranges and $p=f_0'/f_0=4$. This method makes it possible to measure only the variations N_n, since the expected values $\varphi_g \gg 2\pi$.

* Numbers in the margin indicate pagination of original foreign text.

Figure 1 shows a simplified diagram of the interferometer. The transmitting device consists of the decimeter transmitter 1 and the centimeter transmitter 2. The centimeter transmitter represents a frequency multiplier with p = 4 and an amplifier. The output signals of the decimeter and centimeter ranges enter the individual exciters of the pencil-beam antenna which was oriented towards the Earth during communication sessions.

The antenna system on the Earth received signals in the decimeter and centimeter ranges, which entered the receivers 5 and 6. The output devices of these receivers were low-noise parametric amplifiers. A calibration method was used in the receiver system to improve the phase stability of the line: pulsations of a calibrated heterodyne 13, whose frequency differed somewhat from the frequency of the signals, entered the input of the receivers 5 and 6. Pulsations with frequencies equaling the difference in the frequencies of the calibrated heterodyne and the signal, from the output of the receivers 5 and 6 entered the selective amplifiers 7 and 8. The stability of these frequencies was provided by a system of frequency-phase self-adjustment 11, which received the signal from the selective amplifier 7, and which controlled the frequency and phase of the generator of the calibrated heterodyne 12. The signal from the amplifier 7 was also supplied to the p-fold frequency multiplier 9 and then to the system recording the phase 10, which received the signal from the amplifier 8. The EPP-09 and N-102 recorders continuously recorded the values of $\varphi_g(t)$ during the measurement sessions. /757

The automatic interplanetary station Mars-2 was launched on May 19, 1971 and reached this planet on November 27, 1971. There were 16 measurement sessions during the flight between June 29 and November 19. As a rule, the measurement sessions

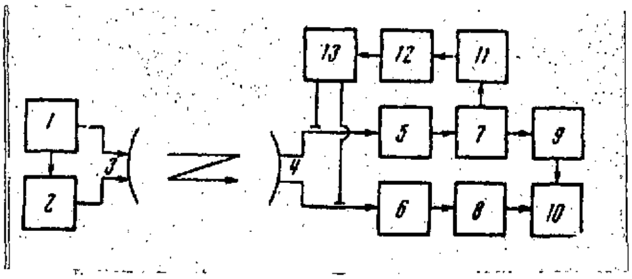

Figure 1. Block diagram of dispersion interferometer

were conducted during the evening and night hours, and lasted from 8 to 50 minutes. The session on July 13 consisted of three intervals which were scattered in time, and the sessions on September 22, September 27 and November 10 were divided into two intervals.

The variations in the integral electron concentration ΔN_n were determined according to formula (1) from recordings of the reduced difference of the phases $\varphi_g(t)$ obtained during the measurement sessions. Figures 2 and 3 give two very different recordings of $\varphi_g(t)$ observed in the sessions of July 18 and September 22. During the session on September 22, the values of φ_g changed slowly and changed their sign, but during the session on July 18 φ_g changed rapidly in one direction, increasing. This indicates that there was a decrease in the integral electron concentration during the measurements. /758

The results of processing the experimental data for certain sessions are given in Figure 4. For purposes of clarity, the curves in the figure are displaced along the time axis with respect to each other.

The basic results of the observations for all of the sessions, and also the conditions under which they were conducted, are given in the table which indicates the date, time (Moscow), beginning and end of measurements, distance D to the station, rate at which the angle $\dot{\beta}$ changed, maximum changes in the integral electron concentration ΔN_n, and their mean velocity N_n.

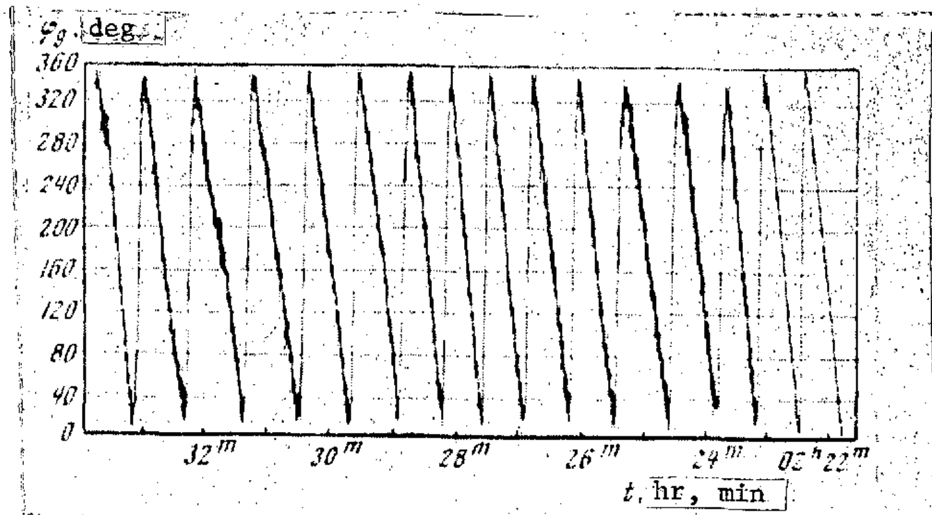

Figure 2. Example of recording of $\varphi_g(t)$ during the session of July 18, 1971.

The measurement time is plotted on the abscissa axis; the phase difference in degrees is plotted on the ordinate axis.

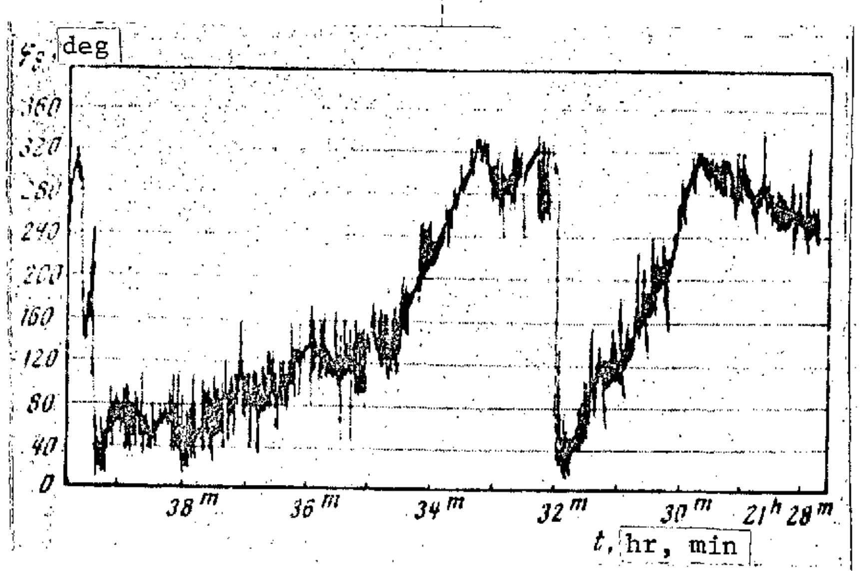

Figure 3. Example of recording of $\varphi_g(t)$ during the session on September 22, 1971

Data, 1971 г.	Session beginning hr, min	Session end hr, min	D, Mill.km	$\dot{\beta}\cdot 10^5$, рад/сек rad/sec	$\Delta N_n \cdot 10^{-11}$, $см^{-2}$	$\dot{N}_n \cdot 10^{-9}$, $см^{-2}$ sec^{-1}
29.VI	05.42	06.00	9,7	−1,8	−10,8; 14,5	−2,6; 2,2
13.VII	00.53	01.05	13,2	2,1	−11,7	−1,6
	01.13	01.24			−8,6	2,9
	01.48	02.05			12,4	1,2
18.VII	02.20	03.12	14,6	0,25	−57	−3,7
24.VII	01.58	02.17	16,5	0,1	1,9	−1,5; 0,8
12.IX	23.15	00.15	46,7	−1,8	6	−1,4; 1,4
22.IX	21.28	21.48	55,8	0,1; −1,2	3,4; −2,8	0,5; −0,5
	22.30	22.46			−4,1	1,0
27.IX	22.19	22.27	60,8	−1,2	0,8; −1	0,6; −0,7
	22.37	22.45			−0,8	−0,8
07.X	23.20	23.28	71,6	−2,7	14,6	3,0
13.X	18.36	18.44	78,2	2,9	5,2	1,5
18.X	21.42	21.51	84,3	−2,7	3,3	2,2
22.X	21.30	21.56	89,6	−1,7	145	9,3
27.X	18.14	18.20	95,0	2,9	−4,2	−1,4
10.XI	19.53	20.00	113,3	−0,2	−0,9	−2,2
	20.12	20.29			18,3; −14,4	6,7; −6,7
15.XI	17.39	17.53	119,9	2,8	−14,5; 2,0	−2,2; 1,7
18.XI	16.42	17.02	123,9	3,7	−31,0	2,9
19.XI	17.01	17.12	125,3	3,4	12,7	2,0

* Commas in numbers represent decimal points

In the group of sessions represented in Figure 4, the variations in the integral electron concentration ΔN_n do not exceed $6\cdot 10^{11}$ $см^{-2}$/ in terms of absolute value. The relations of ΔN_n (t) for these sessions are characterized by small changes in ΔN_n during the observations, with a frequent change in the sign of the derivative $\dot{N}_n$. In the other sessions, the changes in ΔN_n sometimes reach values of $1.5-3\cdot 10^{12}$ $см^{-2}$/. The behavior of curves $\Delta N_n(t)$ for these sessions was more monotonic, although there were brief fluctuations in the integral electron concentration, which comprised 10 - 15% of the total value of ΔN_n during the measurements. During the sessions on July 18 and September 22 (Figure 5), the greatest changes were reported in the integral electron concentration, which exceeded by at least several factors the variations observed during the other sessions. /759

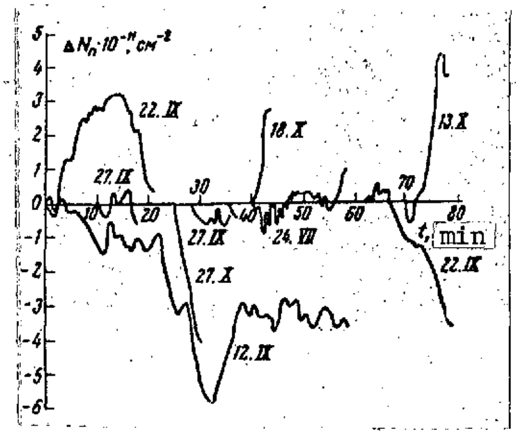

Figure 4. Dependence of ΔN_n on the observation time for sessions on July 24, September 12, September 22, September 27, October 13, October 18, October 27

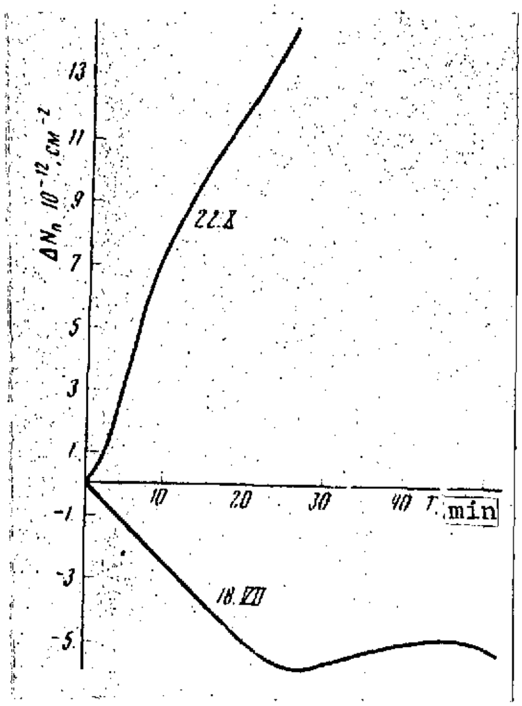

Figure 5

The relations obtained for $\Delta N_n(t)$ were due to a change in the integral electron concentration along the radio communication line passing through the ionosphere of the Earth and the interplanetary plasma. Comparatively small values of variations in ΔN_n, which were recorded during the sessions, are shown in Figure 4. In order of magnitude, these values coincide with changes in the integral electron concentration of the ionosphere of the Earth, which were repeatedly observed by means of artificial Earth satellites [2, 3]. From this point of view, the sessions on September 22 and July 18 are of great interest (Figure 5), where anomalously high variations in ΔN_n were observed. During the session on September 22, there was a monotonic increase in the integral electron concentration by a value of $\Delta N_n \simeq 1{,}45 \cdot 10^{13}$ cm^{-2} in $\approx$ 26 min, to which $\dot{N}_n \simeq 9{,}3 \cdot 10^{9}$ $cm^{-2} \cdot$/sec^{-1} corresponds. In the preceding session of September 18 which was carried out during the same period of time (~ 22 hr), a very slow change in ΔN_n was recorded, by a value of $\Delta N_n \leqslant 3{,}3 \cdot 10^{11}$ cm^{-2}, and in the subsequent session of September 27, which lasted for 18 hours, the value of ΔN_n was $4.2 \cdot 10^{11}$ cm^{-2}. Thus, the change during the session on September 22 exceeded by more than an order of magnitude the variations observed in similar sessions.

Two assumptions may be advanced for the reason for this occurrence. It could have been caused by a powerful fluctuation in the integral electron concentration of the terrestrial ionosphere N_{nu}, or by the passage of a region of high concentration of the interplanetary plasma through the communication line with Mars-2.

To examine the first assumption, it is necessary to know the state of the terrestrial ionosphere during the measurements, and in particular N_{nu}. To determine N_{nu}, information was used on the critical frequencies and half-width layers F_2 based on data from ionosphere stations on the Earth and based on forecasts [4]. Assuming a parabolic model for the region F_2 and assuming [5] that the integral electron concentration above the layer maximum exceeded (by a factor of three) this value below the maximum, we find that the value of N_{nu} equals $1 \cdot 10^{13}$ cm^{-2} during the measurements along the beam on September 22. Consequently, the increase in ΔN_n recorded on September 22 in $\simeq$26 min exceeded by a factor of 1.5 the value of N_{nu}. Such variations in the integral electron concentration of the terrestrial ionosphere were not encountered. In addition, as estimates show, this change cannot be explained by a decrease in the location angle of the station during the measurements.

Thus, the event recorded on September 22 could be caused only by effects of the interplanetary plasma. One of the possible reasons causing changes in the integral electron concentration of the interplanetary plasma could be that pulsed corpuscular streams, moving radially from the Sun, passed through the communication line during the measurement session. These streams were /760 repeatedly recorded during the flight of Pioneer-7 [6]. These events could also have been caused by the communication line being intersected by a rotating sectorial structure of the solar wind, whose boundary, as is known [7], contained a region of high concentration of the interplanetary plasma.

During the session on July 18 from the beginning of the measurements, there was a rapid monotonic decrease in the integral electron concentration over ~26 min at a mean velocity of $\dot{N}_n = -3.7 \cdot 10^9$ cm$^{-2} \cdot$ sec^{-1}. The total decrease during this time was $|\Delta N_n| = 5.7 \cdot 10^{12}$ см^{-2}. The value of $|\Delta N_n|$ reached a minimum value in 02 hr 46 min, after which there was an increase by $\sim 1 \cdot 10^{12}$ см^{-2}, and a subsequent small decrease to the end of the session.

During the preceding sessions on July 13 and the subsequent sessions on July 24, which lasted the same amount of time, there were variations in ΔN_n, whose absolute value did not exceed $1.3 \cdot 10^{12}$ cm^{-2}.

Using the same procedure as for September 22, we may determine the value of the integral electron concentration of the terrestrial ionosphere of the beam N_{nu} during the measurements. This value equals $2.5 \cdot 10^{13}$ cm^{-2}, so that the decreasing ΔN_n observed on July 18 exceeded by 25% the value of N_{nu}, and could not be caused by a change in the location angle of Mars-2, since the session was carried out close to the culmination of the spacecraft. Variations such as this occur in the ionosphere of the Earth [2, 3], but they represent a very rare phenomenon. Therefore, it can be assumed that the change in ΔN_n observed on July 18 could also have been caused by the effects of the interplanetary plasma. Thus, out of 16 measurement sessions carried out on the interplanetary portion of the flight of Mars-2, in two cases there were anomalously high variations in the integral electron concentration, which were apparently caused by the non-uniform structure of the interplanetary plasma.

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16. Abstract

Variations in the integral electron concentration of the space plasma ΔN_n were measured by a two-frequency dispersion interferometer which was placed on the station Mars-2. The experimental data for 16 measurement sessions, which were carried out on the interplanetary section of the flight, are represented in the form of graphs, showing the dependence on time. In two sessions, very large and rapid variations $\Delta N_n \approx 5.7\cdot 10^{12}$ см$^{-2}$ and $14.5\cdot 10^{12}$ см$^{-2}$ were recorded with change rates of $\sim -3.7\cdot 10^{9}$ см$^{-2}\cdot$сек$^{-1}$ and $9.3\cdot 10^{9}$ см$^{-2}\cdot$сек$^{-1}$, which will be explained by the effects of the interplanetary plasma. It is shown that these events could be caused either by pulsed corpuscular streams or by the sectorial structure of the solar wind which intersected the communication line during the measurement session.

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